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New York City Bus Terminal Diesel Emissions Study: Measurement and Collection of Diesel Exhaust for Chemical Characterization and Mutagenic Activity

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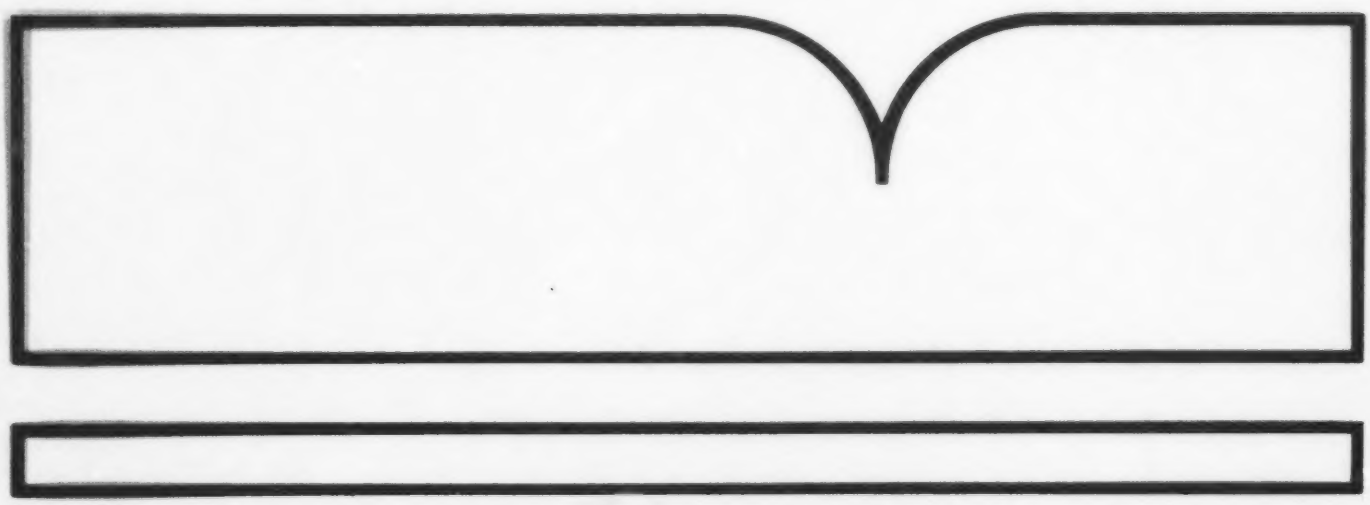

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The New York City Bus Terminal Diesel Emissions Study

Measurement and Collection of Diesel Exhaust for Chemical Characterization and Mutagenic Activity

by

Robert M. Burton
Jack C. Suggs
Robert H. Jungers
Environmental Monitoring Systems Laboratory

and

Joellen Lewtas
Health Effects Research Laboratory

EPA Project Officer
R. M. Burton

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16. ABSTRACT

This paper is directed to individuals concerned with the impact of diesel emissions on the quality of the ambient air and the resulting effects on human health. The study was designed to chemically characterize and bioassay heavy-duty diesel engine exhaust as it exists in the ambient atmosphere. Diesel emission aerosol was collected inside and outside a large NYC bus terminal in which 1400 buses operated daily. Organics were extracted from inside and outside particulate matter and were fractionated into chemical classes. Total extractable organics and each chemical class fraction for both sites were tested for mutagenicity.

Particulate organic analysis showed several significant differences between inside and outside air. Air particle concentration inside the building was nearly 3 times greater than outside with the increase in the <1.7 micron particle size. Although both the small particle and extractable organic concentrations were lower outside the terminal, the mutagenicity of the organics (revertants/μg organics) from outside was nearly 10 times greater than inside the terminal. Results are consistent with studies showing that aged atmospheric organics having undergone atmospheric transformations, have an increased mutagenic response over fresh aerosol emitted directly from combustion sources.

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Research Triangle Park, North Carolina 27711
The NYC Bus Terminal Diesel Emissions Study

Measurement and Collection of Diesel Exhaust for Chemical Characterization and Mutagenic Activity

INTRODUCTION

Emission testing of both heavy-duty diesel engines and light-duty diesel cars using tunnel dilution and filtration to collect diesel particles has shown the organics associated with these collected particles to be mutagenic in the Ames Salmonella typhimurium assay.[1] The mutagenicity of these organics has been shown to be dependent on fuel quality[1] as well as engine type.[2] The organics associated with particle emissions from heavy-duty diesel engines have generally been less mutagenic than the organics from light-duty cars. Fractionation and bioassay studies suggest this is due to a greater concentration of nonmutagenic aliphatic compounds emitted from unburned fuel. Over 90% of the mutagenic activity has been observed in the polar neutral fractions not requiring metabolic activation.[1] Mutagenicity studies of the organics associated with urban ambient air particles have also reported mutagenic activity in the organics extracted from particles.[3] [4]

In order to evaluate the impact of emissions from heavy-duty diesel engines on the mutagenicity of ambient air, this study was designed to compare the mutagenic activity of size-fractionated airborne particles collected inside and outside a large bus terminal. Most diesel exhaust studies have been performed in a laboratory setting. The NYC Port Authority Bus Terminal Study, on the other hand, was designed to collect, measure, chemically characterize, and bioassay diesel exhaust as it exists after becoming resident in the surrounding air. Chamber studies have demonstrated that some of the organic compounds associated with diesel exhaust undergo atmospheric transformation when subjected to ultraviolet light in combination with other pollutants such as ozone, nitrogen dioxide, and reactive hydrocarbons[5] [6] These studies have also shown that the mutagenic response changes with the transformations. A high ambient loading of the emissions aerosol was chosen for the study in order to maximize the amount of information which could be acquired on the character, ambient exposure level, and potential health effects associated with diesel exhaust.

EXPERIMENTAL METHODS

Approach

Since the study was for the specific purpose of characterizing and biologically testing ambient heavy-duty diesel exhaust, a monitoring site was chosen where the majority of the ambient pollutant loading would be originating from diesel powered vehicles operating in a controlled area. Street canyons have the disadvantage of being traffic pattern and meteorology dependent and are further complicated by stationary source emissions and emissions from gasoline powered vehicles. Hence, a semi-enclosed and covered area (terminal) where only diesel powered vehicles operate was selected as the study site. This approach was taken so that excessive

amounts of other pollutants would not be present to cause significant interference tos the study; rather, the other pollutant levels would be present at concentration levels typically found in the large cities.

Site Descr'ption

An agreement was made with the Port Authority of New York and New Jersey to use their bus terminal in Midtown Manhattan, NYC, as the study site. The terminal is an eight-story city-block-size building situated between 8th and 9th Avenues, and between 41st and 42nd Streets. Bus traffic entered and exited the building from third, fourth, and fifth level bridges on the upwind side of the building. Buses remained in the terminal while discharging and reloading passengers, and their engines were left at idle during this time.

Monitoring site #1, designated the diesel exhaust inside monitoring site, was established in the east end of the terminal building on level No. 3, in the vicinity of loading docks 50, 51, and 52. The reported daily count of buses operating in this area was approximately 1,400 per day, Monday through Friday, and 600 per day on Saturdays and Sundays. The majority of buses using the terminal were equipped with Detroit two-stroke heavy duty diesel engines. A representative sample of the bus fuel (DF#2) was obtained and analyzed to be a typical No. 2 diesel fuel with a 0.11% sulfur level, 36.5% aromatics, and a cetane number index of 53.

Monitoring site #2, which was established as an ambient control and background site for the comparative chemical characterization and bioassay screening, was located outside approximately one-half block upwind of the terminal building at the intersection of 41st Street and 9th Avenue. The site was situated in a walkway approximately 50 feet from the street in order to keep roadway aerosol contribution to a minimum.

Monitoring and Sample Collection Design

The major sampling objective was to collect size fractionated aerosol at both the inside diesel site #1 and the outside background and control site #2 in quantities large enough for comparative chemical characterization and screening of the organic fraction. Two Massive Air Volume Samplers (MAVS)[7] [8] at each site were used for this task. The MAVS collects gram amounts of aerosol during 24-hour sampling periods, with the particles separated into three fractions: 3.5-20 microns (Stage I), 1.7-3.5 microns (Stage II), and 0-1.7 microns (Stage III), respectively.

To further define the physical and chemical nature of the exhaust material and to provide information on levels of other gaseous and particulate pollutants present that could cause either interferences or synergistic effects, the following collection and measurement methods were employed at both the inside and outside sites.

A. Total Suspended Particulate (TSP) Mass by the Standard High Volume Sampler Method[9]
B. PM15 Mass by the Dichotomous Sampler Method;[9] fine fraction (0-2.5 microns), and coarse fraction (2.5-15 microns)
C. Organic Vapor Screening by Tenax® polymer collection method[10]

Continuous measurements of sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), total oxides of nitrogen (NO_x), ozone (O_3), carbon monoxide (CO) and total hydrocarbons (THC), were made throughout the study at the inside site; measurements of the same gases, except for total hydrocarbons, were obtained from the New York State Department of Environmental Conservation monitoring site at 240 Second Avenue for determining the background ambient levels in and around the semi-enclosed terminal loading docks.

Monitoring and sample collection operated on a 24-hour sampling schedule for 15 consecutive days. In addition, particulate loadings at site #1 were measured for morning and afternoon 3-hour peak traffic intervals (6 a.m. - 9 a.m.; 3 p.m. - 6 p.m.).

Analysis Methods

TSP High Volume Samples. Gravimetric mass was determined for each sample collected. A one-inch wide strip of each filter sample was composited for total organic extractables and BaP analysis. A second strip was used for 24-hour sulfate and nitrate analysis. Lead analysis was performed from a third strip. Inside and outside filters were kept separated. The remaining portion of the filters were solvent exchanged with dimethylsulfoxide producing two composite (inside and outside) samples for bioassay testing.

PM15 Dichotomous Particulate Samples. Gravimetric mass and elemental analysis by the x-ray fluorescence (XRF) method was determined for both the fine and coarse fractions of each sample.

Volatile Organic Vapor Samples. The chemical vapors collected by Tenax® were recovered by thermal desorption and introduced into a high resolution gas chromatographic column for separation. Characterization and quantification of the compounds were accomplished by mass spectrometry measurement of total ion current and mass fragmentography.

Massive Air Volume Sampler Particulate Matter. The particulate matter (aerosol), collected on teflon coated metal plates, was mechanically removed and samples combined by site location and size fraction. The composite fractions (0-1.7 microns, 1.7-3.5 microns, 3.5-20 microns), respectively, were weighed and the total organic material of each composite sample was extracted with methylene chloride. From each extracted organic sample, aliquots were then prepared for bioassay. Aliquots of the organic extracts were also prepared for chemical fractionation into the following fractions: organic acids, organic bases, nonpolar neutrals (NPN), PNA's, and polar neutrals.[11]

Most fractions were directly analyzed by capillary GC/MS. The fractions enriched in polynuclear aromatic hydrocarbons (PNA's) were further purified by column chromatography, and the collected subfractions were analyzed by GC/MS. A portion of each sample, after fractionation, was prepared for bioassay of the various chemical classes by removal of the fractionating solvent and the addition of dimethylsulfoxide (DMSO). This data will be reported elsewhere.

A third set of aliquots from the total organic extract of each particle size fraction was prepared for benzo(a)pyrene [BaP] analysis.[12]

Mutagenicity Method

The Salmonella typhimurium/microsome plate incorporation assay was performed as described by Ames, et al.[13] with minor modifications.[14] Tester strain TA98 was used with and without metabolic activation. The slope of the dose-response curve (revertants/μg) was determined using a nonlinear model developed by Stead, et al.[15] Bioassay analysis was performed on all MAVS and high volume organic extracts for both inside site #1 and outside site #2 samples.

RESULTS AND DISCUSSION

The traffic count of buses passing by site #1 inside the terminal loading area remained constant throughout the study with a weekday daily average of 1,415 (1336 min., 1440 max.) and a weekend daily average of 615 (579 min., 643 max.). Fifteen 24-hour sampling periods were studied.

Results of aerometric measurements reveal that some pollutants were elevated considerably at the inside site, while others there remained at background level. Particle measurements revealed very high levels of fine fraction aerosol in the terminal building typical of diesel emissions. The 24-hour average TSP inside the terminal was 325 $\mu g/m^3$ while the same TSP outside was 120 $\mu g/m^3$. Dichotomous measurements gave a 240 $\mu g/m^3$ 24-hour average for inside particles less than 2.5 microns in diameter compared to 60 $\mu g/m^3$ at outside site #2. The 24-hour average coarse fraction of the dichotomous sample (2.5-15 microns) averaged 46 $\mu g/m^3$ inside and 20 $\mu g/m^3$ outside. Weekend particle mass levels dropped considerably more inside than outside. Results of 24-hour TSP sulfate, nitrate, and lead levels inside were at the same approximate concentration as at background site #2 (no statistical difference). The outside levels were influencing the inside air for these pollutants. Ratios of sulfate, nitrate, and lead to TSP were all lower inside than at the outside background site.

The MAVS collected adequate amounts of size-fractionated aerosol for the chemical analyses and bioassay. The weight of collected particles in each size fraction is given in Table I. Like the dichotomous sampler measurements, the highest loading of the MAVS occurred in the inside fine fraction samples.

Daily Maximum Hourly Averages - Gaseous Primary Pollutants

Real time continuous measurements, Table I, of the gaseous primary pollutants (SO_2, NO, NO_2, CO, O_3, and THC) showed peaks to occur at 8 a.m. and 5 p.m. at the inside site each day when bus traffic was at a maximum. More variation in maximum hourly averages occurred at the inside site than outside for all gases measured. A summary of gaseous pollutant measurements follows.

Sulfur dioxide (SO_2). Based on 15-day averages, there was no statistical difference between inside and outside maximum hourly averages. Both the Mable Dean Bacon School (outside) site and the Central Park (outside) site SO_2 levels were equivalent to those found inside the terminal, thus indicating very low SO_2 emissions from the buses inside the terminal. The non-elevated inside SO_2 levels are related to the operating conditions of

Table I. Summary of pollutant measurements, NYC Bus Terminal Study.

Sampler Type/Method	24-hr mean conc. $\mu g/m^3$		24-hr max. conc. $\mu g/m^3$	
	Inside	Outside	Inside	Outside
Hivol TSP:				
Mass	325 ± 76	120 ± 35	425	190
Sulfate	16.6 ± 4.8	15.6 ± 5.7	29.6	29.3
Nitrate	2.4 ± 1.8	2.4 ± 3.3	6.3	12.2
Lead	1.7 ± .3	1.7 ± .3	2.2	2.3
Dicot fine mass	240 ± 55	60 ± 21	310	140
Dicot coarse mass	46 ± 24	20 ± 15	95	50
Weekend hivol TSP:				
Mass	228 ± 49	101 ± 36	269	233
Sulfate	21.8 ± 7	21.9 ± 6.5	29.6	29.3
Nitrate	1.9 ± 1.1	2 ± 1.2	4.2	1.2
Lead	1.3 ± .1	1.6 ± .2	1.4	1.8

Gas Pollutant Continuous Measurements	Daily Maximum Hourly Average Mean (ppm)		Peak concentration (ppm)	
	Inside	Outside	Inside	Outside
SO_2	.06 ± .01	.01 ± .02	.08	.10
NO_2	1.4 ± .6	.09 ± .02	2	.17
NO	>7	.04 ± .02	~ 10	.05
O_3	0	.04 ± .03	0	.12
THC	10	-	12	-
CO	18 ± 5	2.6 ± .7	22	2.9

Massive Air Volume Sampler (MAVS)	Mass Collected (grams)	
	Inside	Outside
0-1.7 microns	61.9	14.7
1.7-3.5 microns	1.7	1.2
3.5-20 microns	7.7	6.1

buses. They used a relatively low sulfur fuel and basically operated at There was no significant difference between weekday and weekend maximum hourly values inside the terminal.

Nitrogen dioxide (NO_2). For NO_2 levels, the data indicated more variation in maximum hourly averages for the inside site than outside. The maximum hourly average inside values (mean of 1.36 ppm) were on the average significantly higher than those for outside (mean of .09 ppm) based on 15-day average of maximum hourly values. Weekend maximum hourly values inside were significantly lower compared to weekdays.

Nitric oxide (NO). Throughout the study, maximum hourly inside values of NO were significantly higher than those outside. This is consistent with other diesel exhaust products measurements where NO has been shown to be emitted at high concentration levels.[16]

Ozone (O_3). There were no detectable O_3 levels inside the bus terminal during the study. Outside, the maximum hourly O_3 values ranged from 0.0 to .12 ppm with an average of .04 ppm over the sample period. With the NO levels exceeding 7 ppm and NO_2 levels exceeding 1.0 ppm, it was evident that the O_3 at inside site #1 was reacting quickly with NO to form NO_2.

Carbon monoxide (CO). There was significantly more day-to-day variation in the maximum hourly CO values for the inside site as compared to the outside site. This was apparently due to lower weekend values for inside site #1 maximum hourly averages. Averaged over the sampling period, the maximum hourly average for inside (17.79 ppm) was significantly higher than the outside 10-day average of 2.6 ppm.

Total hydrocarbons (THC). No ambient THC data were available for comparison with inside site #1 levels. Peak hourly maximum averages for inside site #1 was at the 10 ppm level.

Comparison of Inside Diurnal Patterns for the Gaseous Primary Pollutants

The inside generated gaseous pollutants were also analyzed for diurnal variation of concentration. Weekday (Monday-Friday) hourly averages and standard deviations for the study period were computed; weekend (Saturday-Sunday) hourly averages with standard deviations were also computed. As described below for each gaseous pollutant, the diurnal concentration levels for weekdays (1400 buses) were always considerably higher than for weekends (600 buses) for all gaseous pollutants except SO_2.

Sulfur dioxide (SO_2). Inside SO_2 diurnal patterns were similar for both weekends and weekdays. Both were influenced by peak hour traffic activity occurring at 8 a.m. and 5 p.m. each day. The inside average 5 p.m. value was significantly higher during the weekday as compared to weekend levels. The ambient background SO_2 levels did not experience 8 a.m. and 5 p.m. peaks.

Nitrogen dioxide (NO_2). Diurnal patterns indicated significantly higher average levels for weekdays compared to weekends for the 8 a.m. and 5 p.m. inside hourly averages. For weekdays the hourly averages range from .06 ppm during early morning hours (3-4 a.m.) to 1.55 ppm during 5 p.m. rush

hour. For weekends the hourly averages range from .08 ppm during morning hours (3-5 a.m.) to 0.45 ppm during 5 p.m. averaging time. If more ozone had been present in the terminal, much higher NO_2 levels may have been present.

Nitric oxide (NO). Trends indicate a higher inside NO average level during peak hours 8 a.m. and 5 p.m. for weekdays compared to weekends. The values for weekday peaks were beyond the range of the instrument but are estimated to be approximately 10 ppm.

Carbon monoxide (CO). Inside weekday 8 a.m. and 5 p.m. hourly averages were significantly higher than weekend averages during the same averaging times for weekends. During weekdays, hourly averages were slightly elevated compared to weekend averages for hours before 8 a.m. to after 5 p.m. This cannot be concluded about other gaseous pollutants examined in the study. The differences for CO were not significant on an hour-by-hour basis during this time period, even though the hourly averages at 8 a.m. and 6 p.m. were elevated above the rest of the hours in the day.

Total hydrocarbons (THC). Diurnal patterns indicate elevations in inside hourly averages during rush hour activity (8 a.m. to 5 p.m.) for weekday measurements. The 5 p.m. measurement averaged 10.3 ppm during weekdays and is significantly higher than the weekend average of 3.6 ppm.

Effect of Buses on Aerosol Levels

A statistical analysis for describing the relationship between the bus activity and aerosol levels both inside and outside was performed. A paired t-test was used to statistically examine the difference between the inside and outside sites for TSP, dichotomous (fine, coarse, and total), sulfate, nitrate, and lead. The inside measurements were on the average significantly higher (α = .05) than outside for TSP, (0-2.5 micron) and (0-15 micron) particles. These were the only significant differences. There was no significant difference between inside and outside (2.5-15 micron) coarse fraction particles.

Correlation coefficients between daily bus activity and pollutant levels were calculated. Several correlations were determined to be significantly different from zero. These were specifically positive correlations: TSP inside .84; (0-2.5 microns) mass inside, +.74; (0-15 microns) mass inside, .87. Negative correlations included sulfate inside, -.65 and sulfate outside, -.65.

An important observation is that the bus activity does not correlate very highly with inside sulfate, nitrate, and lead. Inside levels of these pollutants were essentially the same as outside. The PM15/TSP ratio was 0.83 for the inside site and 0.84 for the outside site. This ratio is consistent with the PM15/TSP of large city centers and would indicate that diesel exhaust particulate has a growth pattern similar to that of the aerosol of an inner city where gasoline engines and other combustion sources constitute a large portion.[17]

Chemical Analysis

Dichotomous Elemental Analysis. The differences between inside and outside concentrations of the elements determined by XRF analysis were examined on a pairwise basis. Based on five days of simultaneous sampling, for fine particles, the inside concentrations were significantly higher than the outside concentrations for barium, bromine, calcium, chlorine, copper, potassium, phosphorus, sulfur, and zinc. For coarse particles, the only statistically significant difference was for copper, where the inside concentration was higher than the outside measurements. Calcium and phosphorus are related to lube oil consumption while the others are related to fuel composition and combustion and engine and exhaust systemwear.[18]

Volatile Organic Gas Analysis by Tenax. Volatile organic chemicals selected for quantitation were benzene; toluene; xylene; ethylbenzene; 1,1,1-trichloroethane; trichloroethylene; tetrachloroethylene; benzaldehyde; n-octane; and n-heptane. Those selected to represent chemicals associated with diesel engines were octane, heptane, and benzaldehyde. The chlorinated hydrocarbons and general aromatic chemicals were selcted because they are not associated with diesel emissions but are found in the ambient atmosphere.

The quantitation of the volatile organic compounds collected during the study showed that the chemicals which had consistently higher concentration inside were n-octane; n-heptane; 1,1,1-trichloroethene; xylene; and toluene. The chemical which was higher outside was tetrachloroethylene while benzaldehyde, trichloroethylene, benzene, and ethylbenzene were at about the same concentration in and out of the terminal. Week-day concentrations were higher for all 10 chemicals than on weekends.

Total Extractable Organics, BaP and Chemical Class Fractionation. Results of the total extractable organics and BaP analyses are summarized in Table II. From the table it is noted that the highest concentration of aerosol found to be organic was in the inside fine fraction (60.5 $\mu g/m^3$). Outside fine fraction organic concentration was only 9.6 $\mu g/m^3$. BaP was found to be at a higher concentration outside for all three size ranges of particles. The inside/outside ratio for BaP was 0.34 for all three fractions.

Table II. Extractable organics and BaP found in inside and outside aerosol.

Sampler Type/ Method	Particle Conc. $\mu g/m^3$		Organic Conc. $\mu g/m^3$		% Organic Extractable		BaP μg BaP/gram particle	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Hi Vol Sampler 0-30 microns	335	120	14.95	4.08	4.6%	3.4%	15.4	32.0
MAVS, Stage I 3.5-20 microns	58.5	24.0	7.4	1.0	12.6%	4.1%	5.9	25.2
MAVS, Stage II 1.7-3.5 microns	6.5	6.0	0.8	0.3	13.0%	5.2%	11.9	34.3
MAVS, Stage III 0-1.7 microns	214	66.0	60.5	9.6	28.2%	14.5%	0.8	5.9

Results of the chemical class fractionation of the MAVS 0-1.7 micron (Stage III) fine fraction extractable organics are summarized in Table III. Recovery through fractionation was 85% for the inside sample and 75% for the outside sample.

Table III. Chemical class fractionation results for the 0-1.7 micron size fine fraction organics.

Site	Weight of Extract Used for Sub-Fractionation (grams)	Organic Bases		Organic Acids		Polar Neutrals		PNA's		Non polar Neutrals		Recovery	
		Wt. (grams)	%	Wt. (grams)	%	Wt. (grams)	%	Wt. (grams)	%	Wt. (grams)	%	Wt. (grams)	%
#1 Inside	2.24	.053	2.4	.07	3.1	.169	7.5	.061	2.7	1.546	69	1.90	85
#2 Out-side	1.53	.048	3.1	.06	3.9	.166	10.8	.079	5.1	0.784	51	1.14	75

Comparison of the mass distribution of each chemical fraction inside and outside the bus terminal showed several significant differences. The organics from the outside air contained a higher percent mass of the PNA, and the polar neutral fraction. The nonpolar neutral fraction was present at a higher percent mass inside the bus terminal. This appears to be due to higher concentrations of alkanes from unburned fuel.

Mutagenicity of the Particle Bound Organics and Organic Fractions. As shown in Table II, the air particle concentration inside the bus terminal was nearly three times the outside concentration based on the hi vol TSP measurements. MAVS particle data showed the increased concentration of particles inside was due primarily to increased concentrations of particles less than 1.7 micron in size. Although both the small particle and organic concentrations were lower outside the terminal, the mutagenicity of the organics from outside was significantly greater (nearly 10 times) than inside the terminal. Mutagens were detected in the outside samples both in the presence and absence of the S9 metabolic activation system. The mutagenic activity of the air in revertants per cubic meter provides a direct comparison of the mutagenicity of the inside and outside air. Using data from either the hi vol samples or the smallest particles from the MAVS, the outside air was approximately twice as mutagenic as the air inside the bus terminal.

The diesel emissions inside the bus terminal increased the concentration of aliphatic hydrocarbons found in the nonpolar neutral fraction. The higher mutagenicity in the outside ambient air appears to be due to higher concentrations of moderately polar neutral compounds. The highly polar neutral fraction showed more direct-acting mutagenic activity inside the terminal. Table IV summarizes the comparison between inside and outside MAVS Stage III 0-1.7 micron fine fraction particles. It shows the relation between particle mass, extractable organics and mutagenic response expressed as revertants per microgram of organic, revertants per milligram of particles, and revertants per cubic meter of air.

Table IV. Results of bioassay testing for the MAVS Stage III 0-1.7 micron fraction organics

	Inside	Outside
TSP µg/cubic meter of air	214.5	66.8
% Extractables	28.2	14.5
µg organics/cubic meter of air	60.5	9.6
Revertants/microgram of organics -S9	0.07	0.43
Revertants/microgram of organics +S9	0.27	2.79
Revertants/milligrams of particles -S9	19.7	62.4
Revertants/milligrams of particles +S9	76.1	404.6
Revertants/cubic meter of air -S9	4.2	4.1
Revertants/cubic meter of air +S9	16.3	26.7

CONCLUSIONS

From an analysis of the pollutant measurements taken during the study, it can be concluded that the majority of the elevated particulate mass and gaseous pollutant concentrations inside the Bus Terminal were being generated by the heavy-duty diesel powered buses operating within the terminal building. The study provided information about composition and mutagenicity of heavy duty diesel emissions in a semi-enclosed space. The diesel engines are responsible for a very large increase in fine particle loading of the atmosphere, but contribute little to the larger coarse mode fugitive dust loading.

Diesels emit very little nitrate or lead but do emit small quantities of sulfate. Since there was no difference between inside and outside levels

of either NO_3^-, $SO_4^=$, or Pb, it can be assumed that the NO_3^-, $SO_4^=$, and Pb emitted was at levels lower than on the streets of NYC.

The heavy duty diesel engines contributed very little SO_2 to the atmosphere as determined by the comparison of inside and outside levels (no statistical difference). This may be due partially to the relatively low sulfur level of the NO_2 diesel fuel used by the buses.

Higher BaP levels as measured outside should be expected. Its primary source is from fossil fuel (coal) combustion which includes many sources in the New York City area.[19]

The mutagenicity bioassay results clearly show that the outside air is more mutagenic than inside air, even though the fine particle mass inside was elevated considerably. This result is understandable in light of the much higher (10x in the presence of S9) mutagenic potency (rev/μg) of the extractable organic fraction from the outside air.

Gaseous and particulate concentration levels reached their maximums during rush hours when bus traffic was at a maximum, another indication that the buses were elevating the pollutant levels. The NO and NO_2 levels inside the building were significantly elevated, relative to those found outside the building.

The inside and outside differences found in the chemical makeup of the volatile organic vapors and particulate organics cannot be explained easily. Outside organics originate from many sources (including diesel) and had been resident in the atmosphere exposed to radiation and resulting transformation processes for some time. The inside organics were shielded from radiation by the terminal roof and were collected before being resident in the background atmosphere for long periods of time. Atmospheric chemical transformation may play an important role in explaining the higher mutagenic response found outside the building and in the shift of organics to more polar fractions.

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